REMARKS

This preliminary amendment has been sent prior to any Office Action on the merits of the application. The amendment was filed to correct a typographical error. The word "causal" was accidentally used in a number of places instead of the intended word "non-casual". No new matter is being added through this amendment. Neither is the scope of the claims being altered.

It is believed that this application is now in a condition of allowance.

Respectfully submitted,

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<u>The following pages are a version with Markings to show the changes made to pages 3, 6, 8, and 13 of the specification, and to claims 17, 18, and 22.</u>

mitigation techniques must therefore be easily optimized to the channel and somewhat adaptive to changes in the channel due to aging, temperature changes, reconfiguration, and other possible influences.

It would be advantageous if inter-symbol interference caused by energy dispersion in a received NRZ data channel could be minimized.

It would be advantageous if the bit decision thresholds could be modified to take account of the dispersed energy in the neighboring bits in the NRZ data stream.

SUMMARY OF THE INVENTION

Many communication channels exhibit temporal spreading of the signaling waveform when propagating over long distances or over non-linear media. This phenomenon is not effectively addressed by traditional linear equalization techniques due to the non-[causal]casual nature of the impairment. A method is presented to reduce the effects of pulse spreading on hard-decision error rate in communication systems affected by this problem. The method utilizes multiple decision thresholds for each data bit. Post-processing of the multiple decision data is employed to reduce the data to a single hard decision per bit. The multiple data thresholds are adjusted for optimal mitigation of the spreading effect.

The proposed approach to this problem is to perform multiple decisions on every bit with a threshold for each of the above-mentioned conditional probability density functions. The multiple decision data is stored for several bit times, to allow a calculation to be made on the succeeding bits. This calculation is then used to select the threshold most appropriate given the estimated neighbor values. The refined decision is

Fig. 9 is a graph illustrating the operation of the threshold generators as embodied in Fig. 8.

Figs. 10a and 10b are flowcharts illustrating the present invention method for non-casual channel equalization in a communications system.

Fig. 11 is a flowchart illustrating an alternate embodiment of Step 412 of Fig. 10.

Fig. 12 is a flowchart illustrating the training aspect of the present invention method.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 3 is a schematic block diagram of the present invention non-casual channel equalization communication system. The system 100 comprises a multi-threshold decision circuit 102 having an input on line 104 to accept a non-return to zero (NRZ) data stream, and an input on line 106 to accept threshold values. The multi-threshold decision circuit 102 has outputs on line 108 to provide bit estimates responsive to a plurality of voltage threshold levels. A [causal]non-casual circuit 110 has inputs on line 108 to accept the bit estimates from the multi-threshold decision circuit 102. The [causal]non-casual circuit 110 compares a current bit estimate (a first bit) to bit values decisions made across a plurality of clock cycles. The [causal]non-casual circuit 110 has an output to supply a bit value decision for the current bit estimate determined in response to the [causal]non-casual bit value comparisons.

The [causal]non-casual circuit 110 includes a present decision circuit 112, a future decision circuit 114, and a past decision circuit 116. The future

literally, the second comparator 126 supplies a "0" when the NRZ data stream input on line 104 has a high probability of being a "0".

A third comparator 128 has an input on line 104 to accept the NRZ data stream, an input on line 106c to establish a third threshold (Vopt), and an output on line 108c to provide a signal when the NRZ data stream input has an approximately equal probability of being a "0" value as a "1" value. Distinguishing between a "1" and a "0" is a process that is performed by the non-casual circuit 110.

In some aspects of the system, the multi-threshold circuit 102 accepts an NRZ data stream encoded with forward error correction (FEC). Then, the system 100 further comprises a forward error correction (FEC) circuit 130 having an input on line 122 to receive the (first) bit values from the [causal]<u>non-casual</u> circuit 110. The FEC circuit 130 decodes the incoming data stream and corrects bit value in response to the decoding. The FEC circuit 130 has an output on line 106, specifically lines 106a, 106b, and 106c, to supply threshold values to the multi-threshold circuit 102 in response to the FEC corrections. The FEC circuit 130 has an output on line 132 to supply a stream of corrected data bits.

The multi-threshold circuit 102 and the non-casual circuit 110 work together perform a non-casual analysis, regardless of whether the system incorporates the FEC circuit 130. When the multi-threshold circuit 102 receives a NRZ data stream input below the third threshold (Vopt) and above the second threshold (V0), the present decision circuit (of the non-casual circuit 110) responds by supplying a (first) bit value of "1" on line 122, if both the second and third bit values are "0" on lines 118 and line 120, respectively. Otherwise, the present decision circuit 112 supplies

In another aspect of the system 600, the third threshold generator accepts the NRZ data stream input, shown as a dotted line 104. The third threshold generator 606 maintains the average voltage, or a digital representation of the average voltage, on the NRZ data stream input. Note, this is a measurement of the NRZ data stream without regard to non-casual analysis, or the analysis of bit values. The third threshold generator 606 supplies the third threshold (Vopt) at an output on line 106c in response to the measured average. The third threshold can be set <u>to</u> the measured average, for example. Note in this aspect, the input lines 106a and 106b are not needed. With pseudorandom scrambling it assumed that the average voltage is a result of an equal number of "0" and "1" bits being received on line 104. This method of generating the third threshold is very effective when the noise distribution is symmetrical.

In some aspects of the system, the threshold values are initialized using training data. The training data is a stream of predetermined NRZ data, for example, an alternating pattern of "0s" and "1s". The multi-threshold circuit 102 receives NRZ training data input on line 104 and processes it as described above. The non-casual circuit 110 supplies first bit values on line 122 responsive to the received NRZ training data as described above. The system 600 further comprises a training circuit 610 with a memory 612 including the predetermined training data. The training circuit 610 has an input to accept the first bit values from the non-casual circuit 110 on line 122. The training circuit 610 compares the received first bit values to the training data in memory. This comparison operation would be equivalent to the explanation of Fig.

17. (Amended) A non-casual channel equalization communication system, the system comprising:

a multi-threshold decision circuit having an input to accept a non-return to zero (NRZ) data stream, an input to accept threshold values, and outputs to provide bit estimates responsive to a plurality of voltage threshold levels; and,

a [causal]<u>non-casual</u> circuit having inputs to accept bit estimates from the multi-threshold decision circuit, the [causal]<u>non-casual</u> circuit comparing a current bit estimate to bit value decisions made across a plurality of clock cycles, the [causal]<u>non-casual</u> circuit having an output to supply a bit value for the current bit estimate determined in response to the [causal]<u>non-casual</u> bit value comparisons.

18. (Amended) The system of claim 17 wherein the [causal]<u>non-casual</u> circuit includes:

a future decision circuit having inputs connected to the mutli-threshold circuit outputs, the future decision circuit having outputs to supply the current, first bit, estimate and a third bit value;

a present decision circuit having inputs to accept the first bit estimate, the third bit value, and a second bit value, the present decision circuit comparing the first bit estimate to both the second bit value, received prior to the first bit estimate, and the third bit value, received subsequent to the first bit estimate, the present decision circuit having an output to supply the first bit value determined in response to comparing the first bit estimates to the second and third bit values; and,

a past decision circuit having an input to accept the first bit value and an output to supply the second bit value.

22. (Amended) The system of claim 21 wherein the multi-

threshold circuit accepts an NRZ data stream encoded with forward error correction (FEC); and,

the system further comprising:

a forward error correction (FEC) circuit having an input to receive the first bit value from the [causal]<u>non-casual</u> circuit, the FEC circuit decoding the incoming data stream and correcting bit values in response to the decoding, the FEC circuit having an output to supply threshold values to the multi-threshold circuit in response to the FEC corrections and an output to supply a stream of corrected data bits.